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THE INFLUENCE OF SELENIUM ON INCUBATION PATTERNS AND NESTING SUCCESS OF WATERBIRDS AT OURAY NATIONAL WILDLIFE REFUGE, UTAH

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The Influence of Selenium on Incubation Patterns and Nesting Success of Waterbirds at Ouray National Wildlife Refuge, Utah

Bruce H. Waddell and Mark C. Stanger
U.S. Fish and Wildlife Service
Salt Lake City, Utah

Abstract

Egg temperatures and hen attentiveness were studied from 1989-91 on nests near sites known to have high selenium concentrations in an effort to document causes for nesting failures. Temperature and light sensitive radio transmitters were used to monitor incubation patterns in American coots (Fulica americana), mallards (Anas platyrhynchos), gadwalls (Anas strepera), northern shovelers, (Anas clypeata), and redheads (Aythya americana) nests. Mean temperatures of telemetered eggs placed in incubated nests ranged from 32.6°C to 37.8°C and differed only slightly from results obtained in other studies. We found no nesting failures among nests with low levels of selenium, attentive hens, and no predation or abandonment. However, nesting success of attentive hens experiencing no predation but incubating embryos containing high levels (>10 μg/g dry weight) of selenium was poor (29%). Interrelationships of selenium concentrations and incubation patterns are discussed.

Introduction

Recent studies of selenium contamination in the Uintah Basin, Utah, have documented the presence of selenium and other contaminants in soil, water, and biota. Selenium concentrations in water sampled from the Ashley Creek drainage and portions of Ouray National Wildlife Refuge (NWR) exceeded 1000 μg/L and water discharged from agricultural drains into Stewart Lake exceeded 100 μg/L (Stephens and Waddell 1989). Elevated selenium concentrations were documented in fish, wildlife, and habitat at Stewart Lake Waterfowl Management Area (WMA), Ouray NWR, and Ashley Creek (Stephens et al. 1988, Stephens and Waddell 1989). A deformed American coot (Fulica americana) embryo from a failed nest at Ouray NWR had a selenium concentration of 65 μg/g dry weight. Undeveloped or dead embryos from a pied-billed grebe (Podilymbus podiceps) nest and from 3 additional American coot nests contained selenium concentrations ranging from 63 to 120 μg/g (Stephens et al. 1988). Selenium concentrations in coot livers sampled at the Roadside ponds at Ouray NWR ranged from 18 to 43 μg/g (Stephens and Waddell 1989).

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The effects of large concentrations of selenium and other elements on waterfowl embryo development are not yet clearly understood. Heinz et al. (1987) determined that mallards (Anas platyrhynchos) fed 25 or 100 ppm selenium as sodium selenite died or produced deformed embryos or fewer young. Mallards fed 10 ppm selenium as selenomethionine produced young with bill, eye, and foot defects, and had significantly reduced duckling survival. Heinz et al. (1989) found that a mallard diet containing 16 ppm selenium as selenocystine did not impair reproduction, whereas 16 ppm selenium as selenomethionine caused embryonic defects and reduced survival. A dietary concentration of 4 ppm selenium as selenomethionine did not affect mallard reproduction, but 8 ppm selenium impaired reproduction.

Waterfowl incubation patterns and temperatures of naturally incubated embryos using telemetered eggs have not been extensively examined. Huggins (1941), Kossack (1947, 1950) and Cooper (1978) examined egg air cell temperatures of incubating Canada geese (Branta canadensis) and Afton (1979) reported on similar data for northern shoveler (A. clypeata). Caldwell and Cornwell (1975) described the natural incubation environment and behavior of mallards. We monitored waterfowl incubation patterns at Ouray NWR to better understand possible effects of elevated selenium on nesting incubation patterns as possible causes of nesting failure.

Acknowledgements

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Study Area

We conducted nesting behavior studies at Ouray NWR in the spring and summer of 1989 through 1991. Ouray NWR contains approximately 4647 ha (11,483 ac) of mostly wetland habitat 48 km (30 mi) southwest of Vernal, Utah on the Green River (Fig. 1). Elevations on the refuge range from 1402 to 1463 m (4650 to 4800 ft). Since 1961 the refuge has been managed by the U.S. Fish and Wildlife Service, primarily to provide resting areas and nesting habitat for migratory birds.

The arid climate provides an average of about 20 cm (8 in.) of annual precipitation, the majority from late fall through early spring. Summer thundershowers are infrequent, but sometimes provide intense rainfall of short duration. Temperatures in winter frequently drop

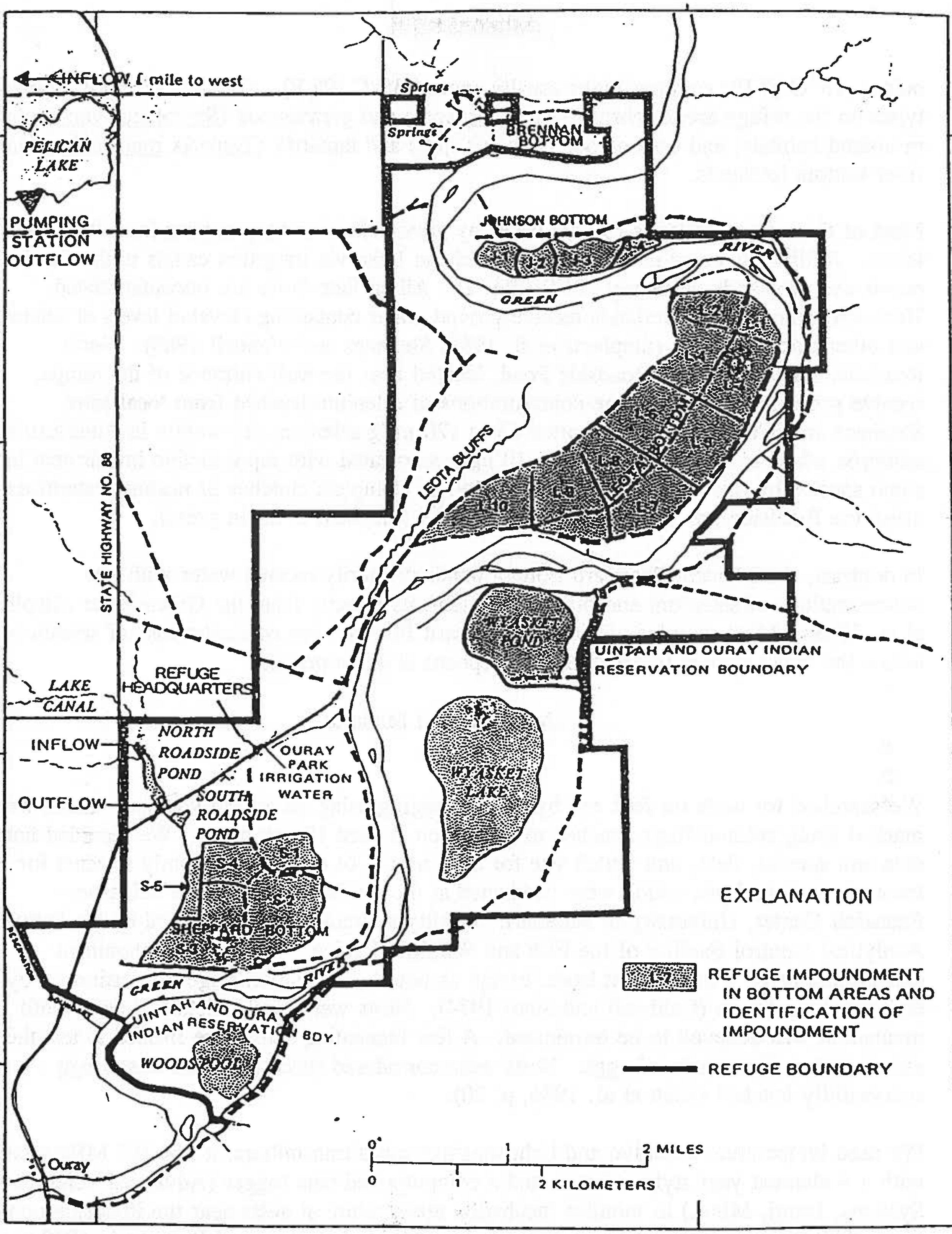

Figure 1. Location of study sites at Ouray National Wildlife Refuge.

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below -18°C (0 F); summer highs usually exceed 35°C (95 F). Dominant natural vegetation types on the refuge are sagebrush (Artemisia spp.) and greasewood (Sarcobatus vermiculatus) in upland habitats, and cottonwood (Populus spp.) and tamarisk (Tamarix ramosissima) in river bottom lowlands.

Most of the refuge wetlands receive water by gravity flow or by pumping from the Green River. Additional water is obtained from Pelican Lake via irrigation canals to the Roadside ponds and croplands on Ouray NWR (Fig. 1). All surface flows are uncontaminated. However, some refuge wetlands receive ground water containing elevated levels of selenium and other trace elements (Stephens et al. 1988, Stephens and Waddell 1989). North Roadside Pond and South Roadside Pond, located near the west entrance of the refuge, receive ground water with large concentrations of selenium leached from local soils. Stephens and Waddell (1989) reported 63 to 120 μg/g selenium dry weight in American coot embryos which is well above the 8 to 10 μg/g associated with reproductive impairment in some species by Skorupa and Ohlendorf (1991). Complete clutches of nesting waterbirds using the Roadside ponds area were unsuccessful (Stephens et al. in press).

In contrast, the adjacent Sheppard Bottom ponds primarily receive water with low concentrations of selenium and other trace elements directly from the Green River (Stephens et al. 1988). Most samples of biota at Sheppard Bottom have concentrations of selenium below the levels known to affect birds (Stephens et al. in press).

Materials and Methods

We searched for nests on foot and by chain dragging using all terrain vehicles. Nests were marked using colored flags attached to vegetation at least 10 feet away. We recorded habitat data and species, date, and clutch size for each nest. An egg was randomly selected for trace element analyses which were conducted at the Environmental Trace Substances Research Center, University of Missouri. Quality assurance was monitored by the Patuxent Analytical Control Facility of the Fish and Wildlife Service. We report contaminant concentrations on a dry weight basis, except as noted. Incubation stage was estimated by embryo examination (Caldwell and Snart 1974). Nests were rarely disturbed again until incubation was believed to be terminated. A few incubating hens were flushed to test the effectiveness of telemetered eggs. Nests were considered successful if at least 1 egg successfully hatched (Klett et al. 1986, p. 20).

We used temperature-sensitive and light-sensitive radio transmitters, a 164-165 MHz receiver with a 4 element yagi style antenna, and a computerized data logger (Advanced Telemetry Systems, Isanti, Minn.) to monitor incubation temperature at nests near the Roadside ponds from 1989 through 1991, at Leota Bottoms in 1989, and at Sheppard Bottoms in 1990; and light intensity at the Roadside ponds in 1990 and 1991 and at Sheppard Bottom in 1990. The data recording system scanned and recorded temperature and (after June 14, 1990) light intensity data from multiple nests simultaneously.

Radio transmitters were enclosed in duck or American coot egg shells prior to placement in the nests. The air cell end of the egg was cut and the embryo removed. The egg shell was air dried and reinforced with a 2-3 mm (0.08-0.12 in) thick dental acrylic layer. After inserting the transmitter and before sealing the shell, air spaces were replaced with paraffin wax to better simulate waterfowl egg density and specific heat (Ellis and Varney 1973). The eggs were sealed and tested before they were placed in nests. The receiver and data logger were secured in a nearby house trailer or ammunition can to protect them from the weather and vandalism. Receivers and data loggers were powered by a periodically recharged external 12 volt deep cycle battery.

Data from the temperature and light sensitive transmitters were recorded at 1 minute intervals in 1989 and 2 minute intervals in 1990 and 1991. Occasionally, small adjustments in frequency were required to compensate for temporary loss of signals. Recorded data were down-loaded to a floppy disk system on a laptop computer every 3 to 5 days. Incubation was considered terminated when data indicated nest temperatures began a diurnal temperature cycle and photo-sensitive transmitters indicated prolonged hen absence.

Statistical analyses of mean incubation temperatures and concentrations of selenium were made using the Mann-Whitney analysis. Attained levels of significance are indicated as "p".

Results

Nest Monitoring

Monitored waterfowl nests at the South Roadside Pond were found within 9 m (30 ft) of water in thick cattail (Typha spp.) vegetation of 60-90% cover. Redhead nests (Aythya americana) were located over shallow water in thick cattail cover. Mallard nests in Sheppard Bottom were on small islands in 70-100% cover consisting of whitetop (Cardaria spp.) or tamarisk. Northern shoveler and mallard nests near the Roadside ponds were located in cattail or hardstem bulrush (Scirpus acutus) stands. Gadwall (A. strepera) nests were usually found in new and old growth Russian knapweed (Centaurea repens) or brush at slightly higher elevations than cattail wetlands. Cinnamon teal (A. cyanoptera) nests (blue-winged teal, A. discors, nests were unlikely and hereafter all teal nests are referred to as cinnamon teal nests) were found along dikes near roads in tall grass/forb vegetation. All American coot nests were located over water in hardstem bulrush stands on North Roadside and Sheppard Bottom 1, in thick cattail on South Roadside, and dead tamarisk at Leota.

Monitoring was initiated in 1989 on June 1 at the Roadside ponds. Nests of an American coot, a redhead and a gadwall at South Roadside Pond, an American coot at North Roadside Pond, and an American coot at Leota were monitored by temperature transmitters only (Table 1).

Table 1.--Concentrations of selenium in sampled embryos and success of corresponding nests monitored at Ouray National Wildlife Refuge, Utah, 1989-91.

Year	Site/Species a	Temperature/ Attendance Monitor	Selenium (ug/g dry weight)	Nest Fate
Roadside Ponds				
1989	N.R./Am. Coot	Yes/No	41.0	Predation
1989	S.R./Am. Coot	Yes/No	75.0	Failed
1991	S.R./Am. Coot	Yes/Yes	67.0	Failed
1991	S.R./Am. Coot	Yes/Yes	67.0	Failed
1989	S.R./Redhead	Yes/No	19.7	Failed
1990	S.R./Redhead	Yes/Yes b	12.6	Failed
1990	N.R./Mallard	Yes/Yes c	24.6	Abandoned
1990	S.R./Mallard	Yes/Yes b	4.45	Successful
1991	S.R./Mallard	Yes/Yes c	15.0	Abandoned
1989	S.R./Gadwall	Yes/No	16.0	Predation
1991	S.R./Gadwall	Yes/Yes	4.9	Successful
1991	S.R./Gadwall	Yes/Yes	9.3	Successful
1991	S.R./N. Shoveler	Yes/Yes	33.0	Successful
Sheppard and Leota Bottoms				
1989	Leota/Coot	Yes/No	--	Successful
1990	Shep1/Coot	Yes/Yes	31.6	Abandoned
1990	Shep1/Coot	Yes/Yes	2.24	Successful
1990	Shep1/Mallard	Yes/Yes	37.9	Successful
1990	Shep1/Mallard	Yes/Yes	3.61	Successful
1990	Shep1/Mallard	Yes/Yes	1.66	Successful
1990	Shep1/C. Teal	No /Yes	2.03	Abandoned
1990	Shep1/C. Teal	No /Yes	--	Predation

a N.R.=North Roadside Pond; S.R.=South Roadside Pond; Shep1=Sheppard Bottom pond 1; Leota=Leota Bottom; Am. Coot=American Coot; N. Shoveler=Northern Shoveler; C. Teal=Cinnamon Teal

b Light/attendance transmitter installed but no data was useable.

c Abandoned immediately, no incubation or attendance data available.

d -- = Not analyzed

Waterfowl incubation ceased by early July whereas American coots continued until late July. Monitoring of all nests studied in 1989, except the Leota Bottom American coot nest, was terminated due to predation or abandonment.

In 1990, nests were monitored from May 24 through July 19. We monitored 1 redhead and 2 mallard nests at the Roadside ponds. Although several American coots at both Roadside ponds exhibited territorial behavior, we found no American coot nests or chicks at either pond. In 1990, we monitored 3 mallard, 2 American coot and 2 cinnamon teal nests at Sheppard Bottom.

During 1991, the study was restricted to waterbird nests near the Roadside ponds. Monitoring of waterbird nests was conducted from May 8 to July 23. Two gadwall, 1 northern shoveler, 1 mallard and 2 American coot nests were monitored, all on or near the South Roadside Pond.

Selenium, Arsenic, and Mercury Concentrations

Concentrations of selenium found in Sheppard Bottom embryos were generally lower than concentrations found in embryos sampled from the Roadside ponds area (Table 1). Geometric mean concentrations of selenium in embryos from all monitored nests sampled from the Roadside ponds and Sheppard Bottom were 21 ($n = 13$) and 5.7 ($n = 6$) $\mu g/g$, respectively. These were significantly different ($p \approx 0.06$). Four nests were abandoned prior to the hatching date and 2 nests were depredated prior to determination of nest fate. Even without those nests in the data set, the mean concentrations were significantly different ($p \approx 0.08$). One cinnamon teal nest at Sheppard Bottom Pond was abandoned on the day of hatch; it had one egg with live embryo pipping the egg when checked, but all eggs failed to hatch. This was included with abandoned nests even though it would have likely hatched if undisturbed.

Concentrations of selenium found in live embryos from 2 nests in Sheppard Bottom were 37.9 and 31.6 $\mu g/g$ which were much larger than expected. Neither embryo had any observed deformities. The first nest, an American coot, was abandoned; however, the second nest, a mallard, was successful. All other concentrations of selenium in embryos sampled from Sheppard Bottom were relatively low, ranging 1.7 to 3.6 $\mu g/g$. In contrast, concentrations of selenium in embryos from the Roadside ponds were all > 4 $\mu g/g$.

A sample egg from the American coot nest monitored in the Leota Bottom was not analyzed for selenium, however, this data has been included in our analyses. Detailed studies of American coots and other waterbirds indicated Leota Bottom was free of selenium problems. Of 26 American coot eggs analyzed from Leota Bottom, concentrations of selenium in the embryos ranged from 1.3 to 3.8 $\mu g/g$, with a geometric mean concentration of 2.0 $\mu g/g$ (Stephens et al. 1992).

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Concentrations of selenium in embryos from 2 redhead and 3 American coot nesting attempts at the South Roadside Pond where incubation monitoring continued after the expected hatching date ranged from 13 to 75 μg/g with a geometric mean concentration of 38 μg/g, as compared to a range of 1.7 to 38 μg/g and a geometric mean of 6.6 μg/g for 8 successful nests from all sites. Concentrations of selenium were significantly larger ($p \approx 0.03$) in embryos from nests that failed to hatch, than in embryos from nests that hatched at least 1 egg. Embryos from the 3 failed American coot nests appeared normal during early incubation (4, 1, and 7 days). After failing to hatch, additional embryos of both 1991 American coot nests were examined and were found to be deteriorated to a homogenous paste with no distinguishable embryo. In a 1989 redhead nest, the embryo sampled at 11 days incubation appeared normal. A dead embryo with reduced legs and feet, a deformed beak, and lacking eyes was collected from this same nest after the nest failed to hatch and eggs were subsequently abandoned. The initial redhead embryo sampled in 1990 appeared normal. Additional embryos collected from this nest after the expected hatching date had died at various stages of development but had no apparent external deformities.

Of 21 nests monitored by telemetry, 3 suffered predation, 5 failed to hatch any eggs, 4 were abandoned prior to successful hatching of any eggs, and 9 were successful in hatching at least 1 egg. Two of 7 nests (29%) that were not depredated or abandoned and had sample embryo concentrations of selenium of 10 μg/g or greater, were successful.

Concentrations of arsenic and lead were near or below their respective detection limits of 0.3 and 0.2 μg/g. Mercury concentrations were between <0.02 and 0.356 μg/g.

<u>Incubation temperatures</u>

Data analysis included identifying and eliminating spurious data collected when telemetry equipment recorded inaccurate data. Fluctuations of up to 0.5°C in temperature between 2 minute scans were frequent. Maximum possible temperature change was estimated by immersing temperature sensitive transmitters in an ice-water bath. We determined that transmitter temperature changes of more than 1°C per minute between 25°C and 10°C are unlikely. Temperature fluctuations beyond 3 standard deviations of the mean temperature change exceeded this criteria, were considered a result of malfunctioning equipment, and were eliminated (Fig. 2). Blocks of scans where recorded temperatures were erratic from scan to scan were considered unreliable data and deleted.

Two of 19 nests containing temperature telemetered eggs were abandoned before incubation temperatures could be obtained. Mean temperatures of 6 telemetered eggs from Sheppard and Leota bottoms ranged 35.0°C to 36.8°C for all species (Table 2). Mean temperatures of 11 eggs at the Roadside ponds ranged 32.6°C to 37.8°C. Mean temperatures between areas were not significantly different ($p \approx 0.63$). The gadwall embryos monitored in 1991 at the South Roadside Pond had concentrations of selenium of 4.9 and 9.3 μg/g and the lowest mean temperatures (Tables 1, 2). However, they were successful.

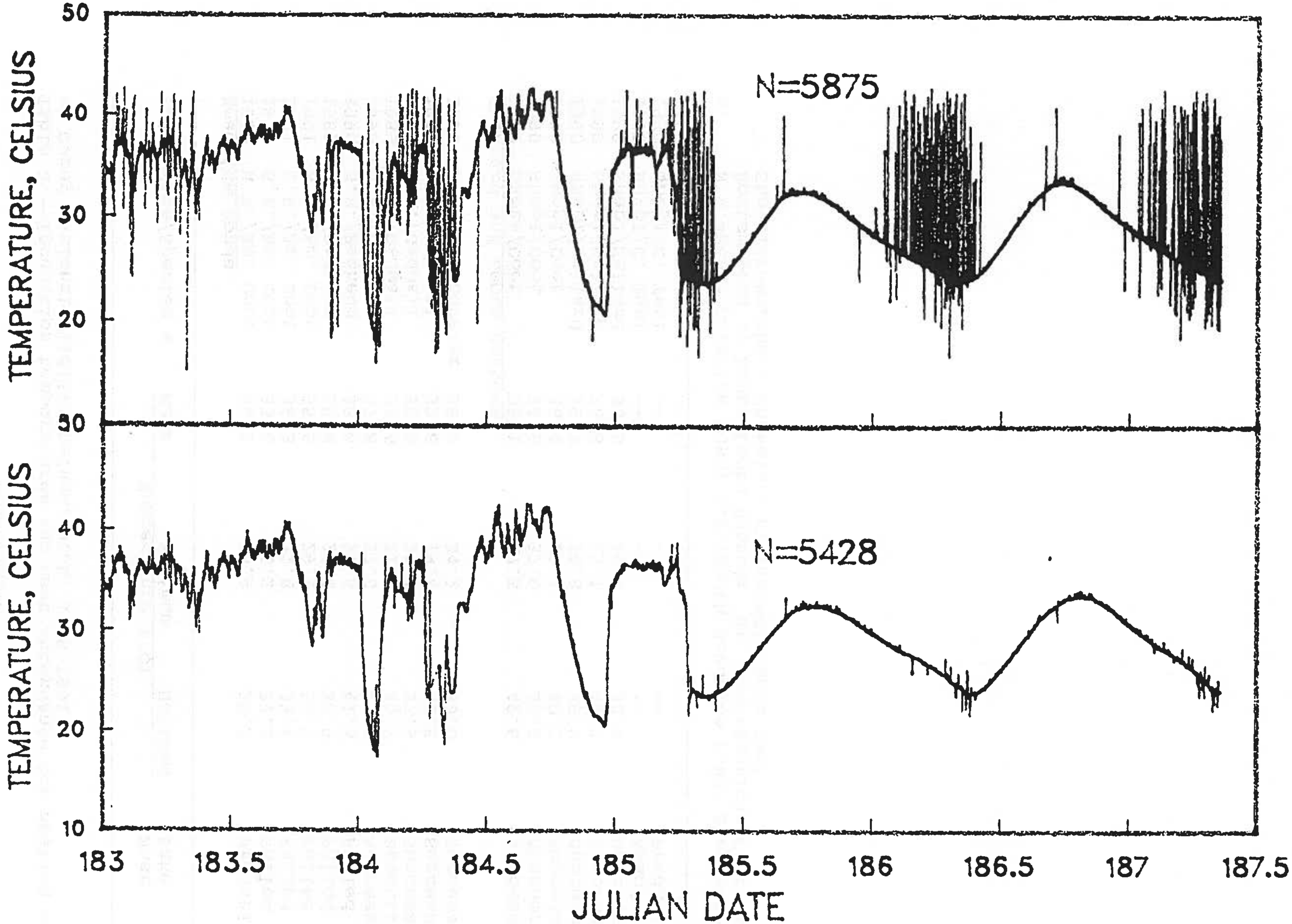

Figure 2.—-Temperature profile of a telemetered American coot nest in Leota Bottom at Ouray National Wildlife Refuge before (top) and after (bottom) spurious data were eliminated.

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Table 2.--Incubation temperatures and nest attendance for nesting waterbirds at Ouray National Wildlife Refuge, Utah, 1989-1991.

Year	Site/Species a	Temperature (°C)			Nest Fate	Attendance (%)
		Mean	Minimum	Maximum		
Roadside Ponds						
1989	N.R./Am. Coot	36.2	25.9	39.3	Predation	--
1989	S.R./Am. Coot	35.4	28.2	37.9	Failed	--
1991	S.R./Am. Coot	36.3	22.8	39.4	Failed	67
1991	S.R./Am. Coot	35.5	29.1	38.7	Failed	70
1989	S.R./Redhead	35.8	29.6	38.9	Failed	--
1990	S.R./Redhead	35.6	27.5	41.8	Failed	--
1990	S.R./Mallard	37.8	27.8	42.4	Success	--
1989	S.R./Gadwall	35.6	21.1	40.2	Predation	--
1991	S.R./Gadwall	33.6	21.4	37.9	Success	69
1991	S.R./Gadwall	32.6	19.4	42.5	Success	74
1991	S.R./N. Shoveler	35.2	24.2	39.0	Success	69
Sheppard and Leota Bottoms						
1989	Leota/Coot	35.1	17.5	42.6	Success	--
1990	Shep1/Coot	36.6	32.9	39.8	Abandoned	70
1990	Shep1/Coot	36.4	23.1	40.2	Success	62
1990	Shep1/Mallard	35.7	19.8	38.9	Success	72
1990	Shep1/Mallard	36.8	29.1	42.7	Success	78
1990	Shep1/Mallard	35.0	26.9	38.4	Success	57
1990	Shep1/C. Teal	--	--	--	Abandoned	50
1990	Shep1/C. Teal	--	--	--	Predation	73

a. N.R.=North Roadside Pond; S.R.=South Roadside Pond; Shep1=Sheppard Bottom pond 1; Leota=Leota Bottom; Am. Coot=American Coot; N. Shoveler=Northern Shoveler; C. Teal=Cinnamon Teal

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We evaluated the success of incubation for 14 of the 17 nests in which we monitored incubation temperatures beyond the expected hatch date. The arithmetic means of 35.4°C for the 9 successful nests and 35.7°C for the 5 nests in which the hen continued to incubate beyond the expected hatch date and hatching failed for unknown reasons, were not significantly different ($p \approx 0.60$). Concentrations of selenium of 8 ppm for population estimates and 10 ppm for individual eggs were considered lower concentrations associated with reproductive impairment in some species (Skorupa and Ohlendorf 1991). Arithmetic mean temperatures of telemetered eggs for nests below and above the estimated threshold of 10 ppm selenium were 35.4 and 35.6°C, respectively ($n = 6,7$). These were not significantly different ($p \approx 1.0$). Mean temperatures were not significantly different ($p \approx 0.96$) between the 6 depredated nests (35.4°C) and the 10 abandoned nests (35.8°C).

The mean temperature for the 14 nests that completed incubation (35.5°C) did not differ from the mean for the 3 nests (36.1°C) that prematurely terminated ($p \approx 0.32$). We detected no interspecific differences among these nests (Table 3).

Table 3.--Telemetered egg temperatures at Roadside, Sheppard Bottom 1(S1) and Leota ponds for different species groups at Ouray National Wildlife Refuge, 1989-1991.

			Temperature (°C)		
Species	Site	Nests	Mean	Min.	Max.
American Coot	S1/Leota	3	36.0	17.5	42.6
	Roadside	4	35.9	22.8	39.4
	All Sites	7	35.9	17.5	42.6
Mallard	Sheppard 1	3	35.8	19.8	42.7
	Roadside	1	37.8	27.8	42.4
	All Sites	4	36.3	19.8	42.7
Redhead	Roadside	2	35.7	27.5	41.8
Gadwall	Roadside	3	33.9	19.4	42.5
Northern Shoveler	Roadside	1	35.2	24.2	39.0

Data are limited and offer little information about the failed South Roadside American coot and redhead nests of 1989. Only 578 and 824 temperature scans covering 16.1 and 17.9 hours, respectively, were available for these nests (Table 2). Temperatures for these nests were similar to those of successful nests.

Warming and Cooling Rates

Eggs warmed more rapidly when the hen returned to the nest than they cooled at her departure. For example, a mallard egg warmed at an average rate of 4.9°C/hr at the end of

33 incubation recesses, but cooled at an average of 3.5°C/hr immediately following 38 hen departures. This cooling rate is less than 10% of the maximum cooling rate of transmitters immersed in ice-water. Periods of rapid warming lasted an average of 51.9 minutes (standard error = 23.0 min) before temperatures began to level off. Rapid cooling periods averaged 50.2 minutes (standard error = 20.6 min) before the cooling rate slowed.

Ducks left their nests about 2-3 times a day. Breaks in incubation by ducks were less frequent, somewhat more predictable, and of longer duration than breaks by American coots (Fig. 3). American coot incubation patterns were typified by short duration and frequent alternating periods of attentiveness and incubation recess. Telemetered eggs in American coot nests experienced more frequent and less extreme fluctuations in temperature than waterfowl. During recesses, coots were often nearby and would not flush great distances if disturbed while on or near the nest.

Nest Attentiveness

The percent of time on the nest, as monitored by telemetered eggs indicating light intensity in the nest during daylight hours, ranged from 50-78 among species. Daylight was considered from 730 AM to 9 PM for these analyses. Mallards at Sheppard Bottom displayed daytime attentiveness of 57, 72, and 78% among three hens producing successful nests. Two successful American coots at Sheppard Bottom were on the nest during daylight hours 70 and 62%. Attentiveness of two cinnamon teal hens to nests monitored with only photo-sensitive transmitters (no temperature sensitive transmitters) was 73 and 50%. The first nest suffered predation and the latter nest was abandoned as eggs were hatching, probably due to frequent human disturbances on an adjacent road. Nest attendance at the Roadside ponds ranged from 67 to 74% for 5 nests monitored (Table 2); this was within the range for successful nests at all sites.

Because photo-sensitive transmitters are useful only during daylight hours, the percentage of time spent incubating in any 24 hour period was greater if hens are assumed to be on the nests from dusk to dawn as Breckenridge (1956) found in wood ducks (Aix sponsa). Hens often returned to the nest just before dusk and usually were on the nest in the morning. Temperature sensitive transmitters were inoperable during early morning hours from about 1:00 to 9:00 for some nests. Nocturnal temperature data, where available, indicated hens were present. The low number of rapid temperature decreases and similar evening and morning transmitter temperatures suggest that nocturnal hen attentiveness was relatively high.

Daily attentiveness of American coot hens the first few days of incubation ranged between 63 and 73%. As incubation progressed, hen attentiveness decreased to as low as 45% during hatching. Mallard attentiveness showed similar patterns as incubation progressed. However, initial daily attentiveness in early incubation was as high as 82% and slowly decreased to about 73% just prior to hatching. Cinnamon teal attentiveness ranged from 70 to 79% over several days for a relatively undisturbed nest as compared to only 50% attentiveness for a cinnamon teal nest about 4 feet from a maintenance road.

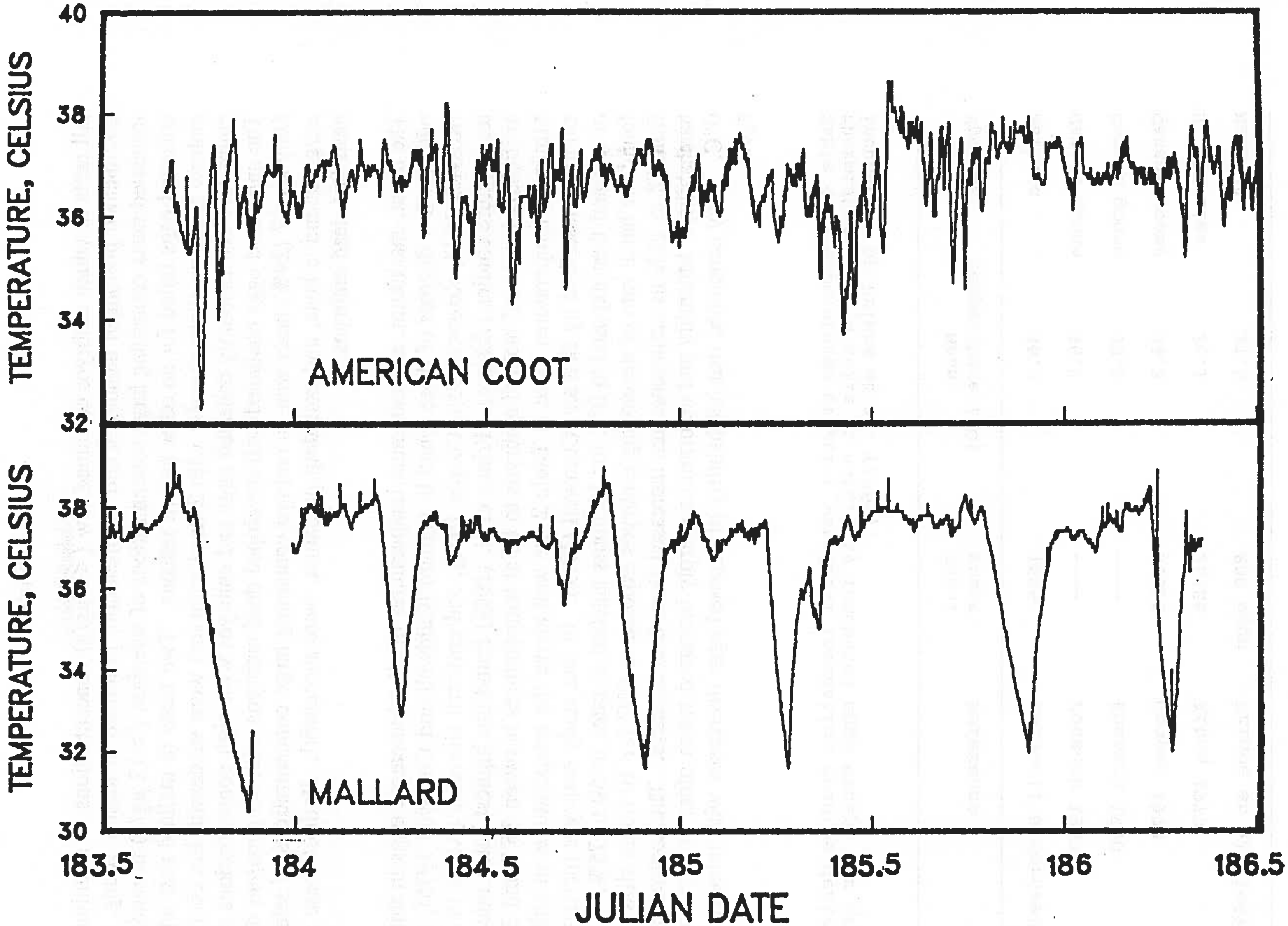

Figure 3.--Three day telemetered egg temperature profile for American coot and mallard nests at Sheppard Bottom, Ouray National Wildlife Refuge, 1990.

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Discussion

All nests in which embryos contained low (<4 μg/g) concentrations of selenium, and with documented prolonged incubation and no predation, produced at least 1 young. However, 5 incubated nests containing large concentrations of selenium (>12 μg/g) in randomly collected eggs failed for no other known reasons. Two nests (a mallard nest with 1 dead embryo and a northern shoveler with 2 dead embryos) were successful but contained dead embryos. The randomly collected eggs had embryos with high concentrations of selenium. The unhatched eggs contained well developed dead embryos with no apparent deformities. Only 2 of 7 (29%) nests with an embryo containing large concentrations of selenium (> 10 μg/g), attentive hens, and excluding predation, were successful. Both of these successful nests had dead embryos.

The mean, maximum, and minimum temperatures of all telemetered eggs in this study are within a few degrees of those found in mallard (Caldwell and Cornwell 1975), Canada goose (Kossack 1947, Kossack 1950, Cooper 1978), and northern shoveler (Afton 1979) egg cell temperature studies (Table 4). Prince et al. (1969) found the highest hatch rate for artificially incubated mallard embryos to be at temperatures between 36.7 and 38.3°C. Minimum temperatures listed in Table 2 are well above the temperatures of chilled mallard embryos described by Batt and Cornwell (1972). In that study embryos incubated for 6 days or less and then exposed to 0°C for 10 hours hatched at rates of 50 to 75%. They also found the hatch rate of developing embryos exposed to 8°C for 10 hours slowly decreased from 58 to 15% as embryonic age increased from 6 to 24 days. The control had 43.7% hatchability. Mortality and deformities sharply increased when older embryos were chilled at 0°C. They concluded that hatchability of exposed eggs decreases with increased embryonic age.

Table 4.--Temperatures of prior waterfowl incubation studies derived from thermistors in egg cells of naturally incubated eggs except for artificial incubation by Prince et al. (1969).

Species	Mean Temperature (°C)	Total scans	Reference
Mallard	36.3	1655	Caldwell & Cornwell 1975
Canada goose	36.9	----	Kossack 1947
Canada goose	38.5	----	Kossack 1950
Canada goose	34.3	11520	Cooper 1978
N. shoveler	36.1	25186	Afton 1979
Mallard	37.5	800 eggs	Prince et al. 1969 (lab)

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Moreng and Bryant (1955) cooled various aged chicken embryos from 37.5°C to 0°C in about 55 minutes. Except for 6 day old embryos, at least half of the embryos from each age group up to 17 days old survived as compared to 74.5% for unexposed (control) embryos. They also found in a similar treatment that embryos cooled slowly (210 min.) experienced a higher hatching rate than rapidly cooled embryos. Moreng and Bryant (1954a:856-858) found exposure to -23°C had little effect when exposure time ranged from 70 to 90 minutes. Hatchability of chicken embryos after exposure to -23°C ranged from 69.2 to 96.7% for embryos 0 to 16 days old (Moreng and Bryant, 1954b). Embryonic survival improved for all aged embryos when exposure time was slightly less (Moreng and Bryant 1954b). Moreng and Shaffner (1951) determined the average low internal egg temperature lethal to chicken embryos to fall between -2°C and -1°C. These figures were based on exposure to -23°C for 70 to 95 minutes, long enough to kill half of the embryos. It is unknown whether cold tolerance in chicken embryos was at least partially due to extensive crossbreeding.

Batt and Cornwell (1972) found that hatchability of unincubated mallard eggs was unaffected after exposure to 0, 4, or 8°C until exposure exceeded 5 days at 0°C or 8 days at 4°C, after which survival sharply decreased. Hatchability of unincubated eggs was unaffected after 10 days of treatment to cold at 8°C. We found no reason to believe exposure prior to incubation damaged any embryos. Temperatures at Ouray NWR never fell below 0°C during any incubation period. For example, transmitter temperatures of our earliest mallard nest prior to incubation fluctuated between 15.8 and 29.6°C. Sporadic hen attentiveness during laying probably resulted in minimal embryonic development prior to incubation (Caldwell and Cornwell 1975).

Attentiveness of hens initiating incubation increased when laying ceased and remained relatively high through early and middle incubation periods but decreased as embryos were about to hatch. Transmitter temperatures often displayed a higher variability as hatching approached because hen attentiveness decreased. We believe that embryos near full development had less temperature variability than indicated by transmitter eggs due to their metabolic heat production. Drent (1970) and Caldwell and Cornwell (1975) attributed the progressive increase of average daily egg cell temperature during incubation to embryo thermogenesis. Afton (1979) obtained similar results from northern shoveler incubation studies. We expected transmitters lacking internal heat production to cool slightly faster and maintain slightly lower temperatures than developed embryos during late stages of incubation.

Conclusions

Nesting behavior of American coots and ducks, including incubation temperature and hen attentiveness, did not appear to differ from site to site. Egg temperatures were similar in areas of high and low ambient selenium concentrations. The data suggest that nesting success was not dependent on small differences in hen attentiveness, changes in egg temperatures, or in mean incubation temperature. American coot and redhead nests on North and South Roadside ponds failed for no known reasons except high concentrations of selenium. Embryos from nests with high levels of selenium were deformed, died during development, or failed to develop. Nesting success was nearly 100% for nests with eggs having low selenium concentrations, but success was poor for nests with high selenium concentrations.

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